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Hydrologic analysis of a residential green infrastructure project Cincinnati OH, USA

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Study motivation

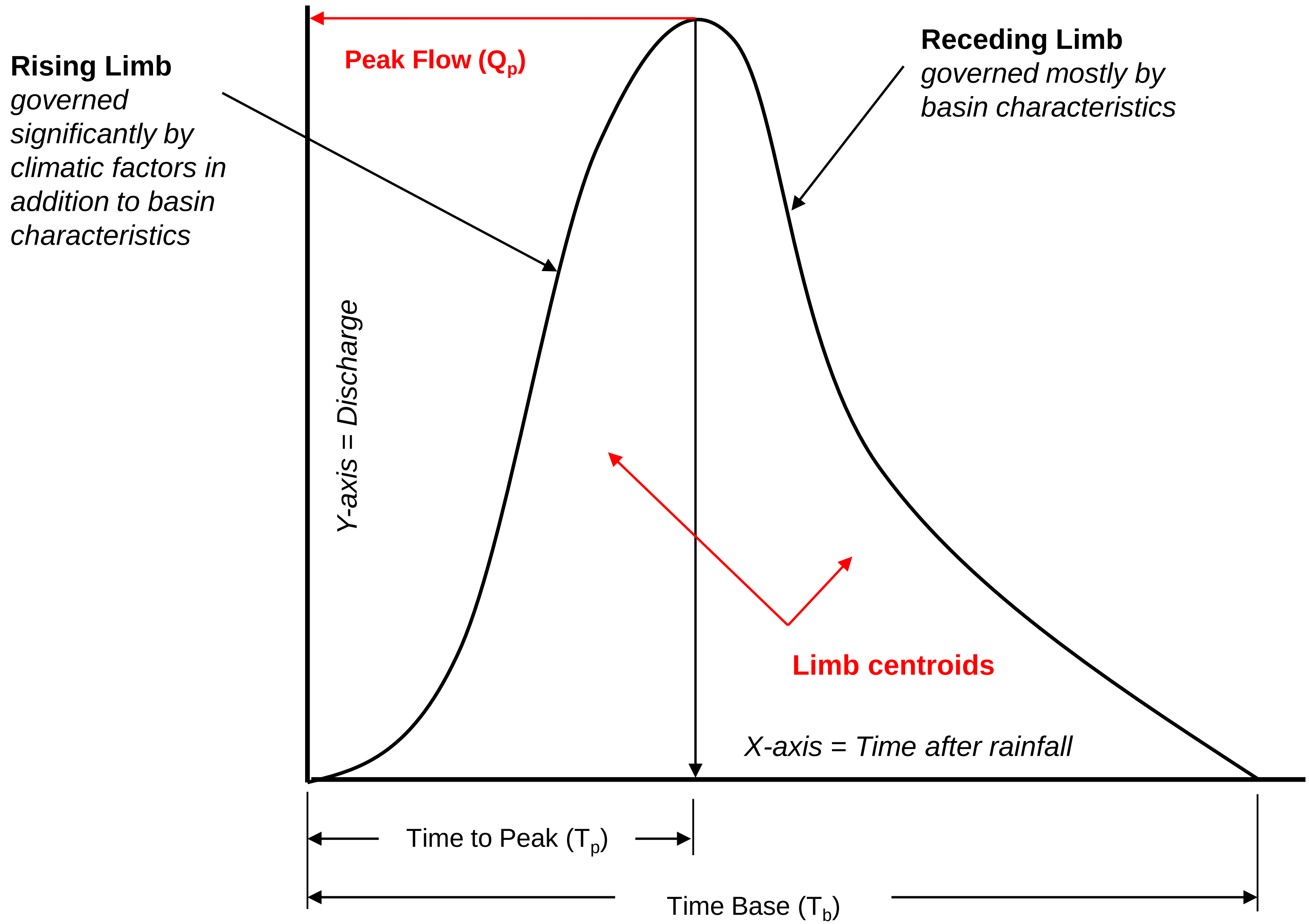
- Context
  – current strains on municipal budgets throughout the US

- Goal
  – demonstrate effective implementation of low-cost methods to reduce some typical impacts of urbanization on stormwater discharge, such as:
    - increased flashiness
    - decreased infiltration
    - degraded water quality (another talk)

- Approach
  – Elicit voluntary adoption of green infrastructures by homeowners

Conceptual storm response

goal is to "flatten" hydrograph



Background

- We wished to ascertain whether green infrastructure could be successful in “suburban” areas (accepted, effective)

- In the USA we do not have a regulation that covers stormwater quantity on private property

- We used a reverse-auction to elicit (voluntary) participation

- Rain barrels (165) and a rain garden (85) were installed on the properties of the lowest bidders during 2007 and 2008

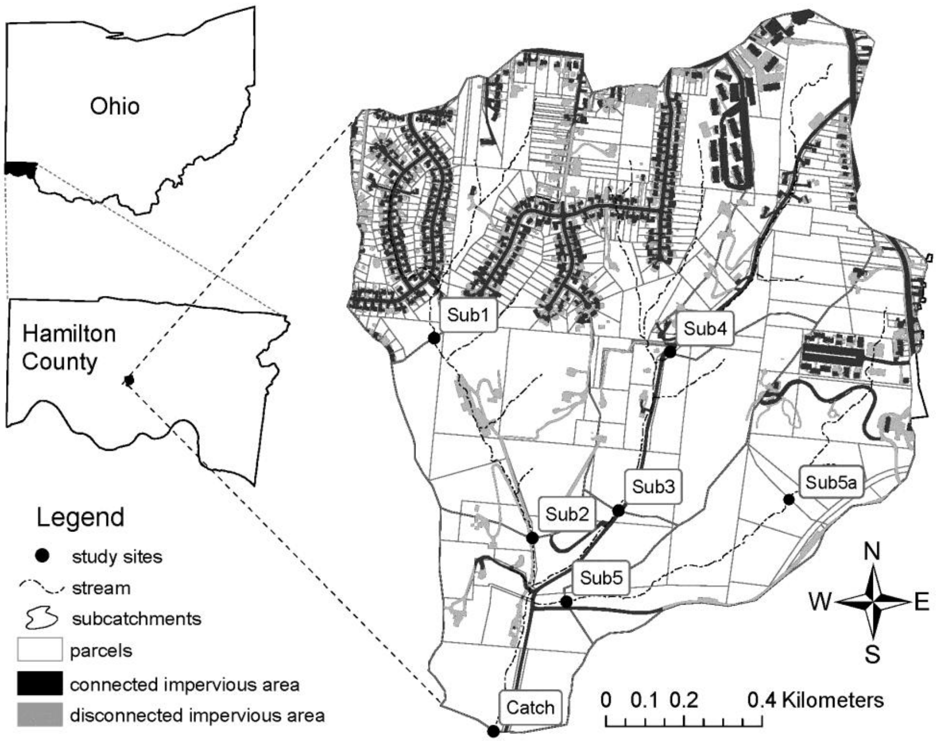
Green infrastructures

Rain garden
($16\text{-m}^2 \times <1\text{-m}$)

Rain barrel
(284-liters or 75-gal.)

Site details and experimental design

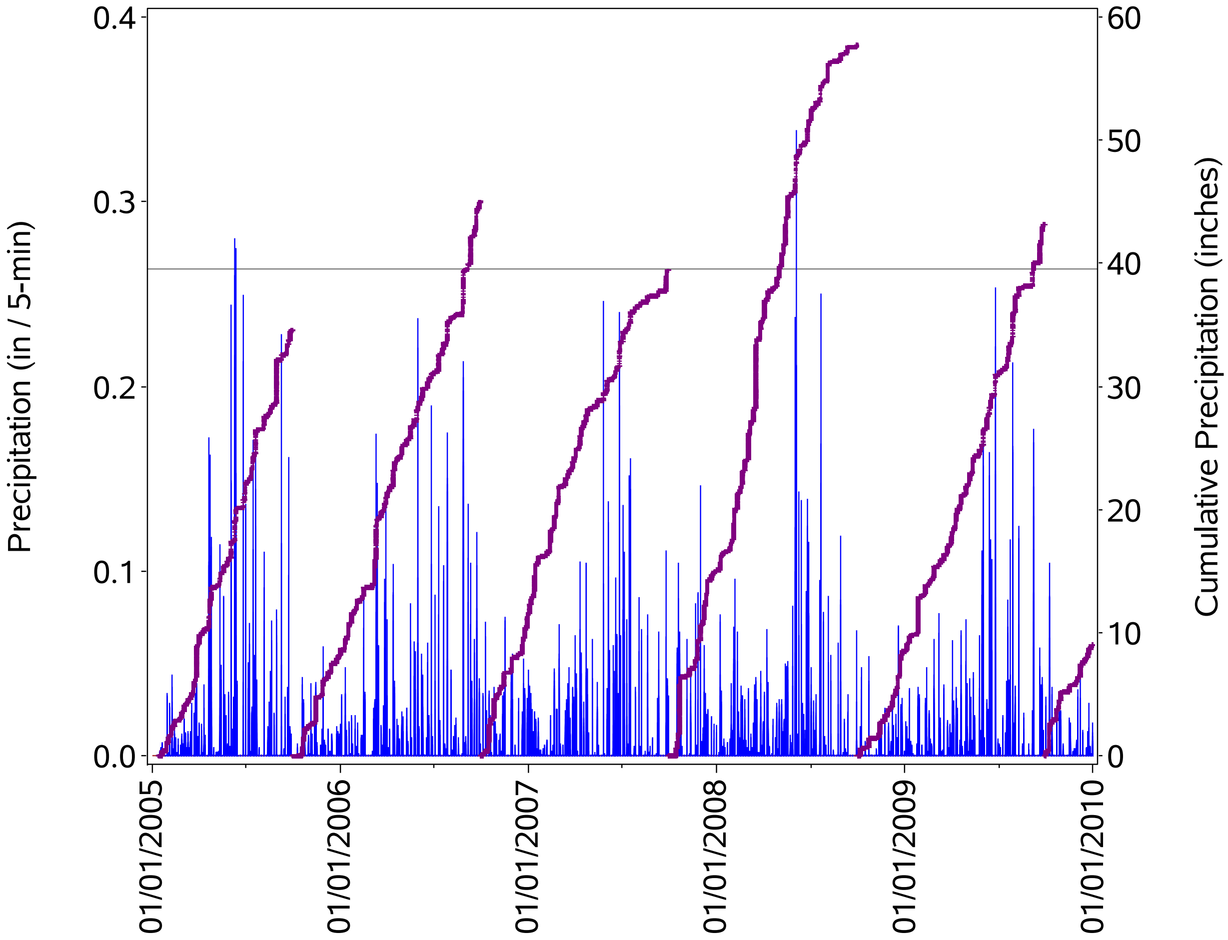
- 1.8 km^2 watershed
- 13% Total Impervious Area
- Treated 1/3 TIA (4% basin)
- Mixed land uses (residential, forest, farm)
- before-after-control-impact (BACI) study design
- Gages for multiple control (2) and treatment (3) sub-basins



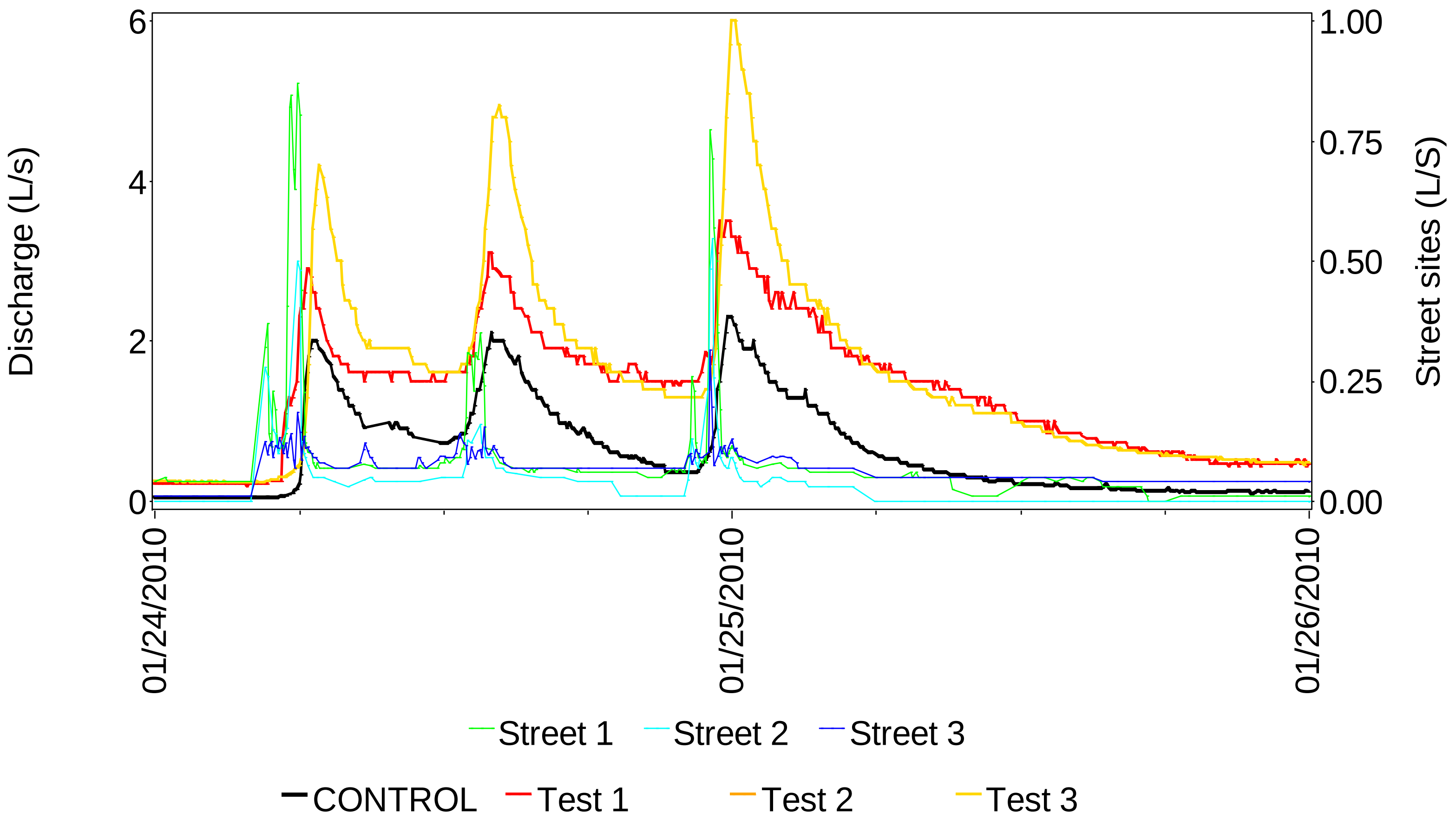
BACI: model components

- (lagged and led) cross-basin discharge in <u>control</u> sub-basins (Control part of BACI design)
- (baseline / treatment) study period (Before-After part of BACI design)
- (lagged) precipitation and discharge in <u>treated</u> sub-basins (Impact part of BACI design)
- Individual treatment of rising versus falling hydrograph limbs (somewhat different influences)
- lagged discharge in <u>treated</u> sub-basins (AR / MA error process)
- background linear trend through time (precautionary, for nuisance effects)
- Seasonality (sinusoid based on paired sine and cosine of 2π•year-fraction

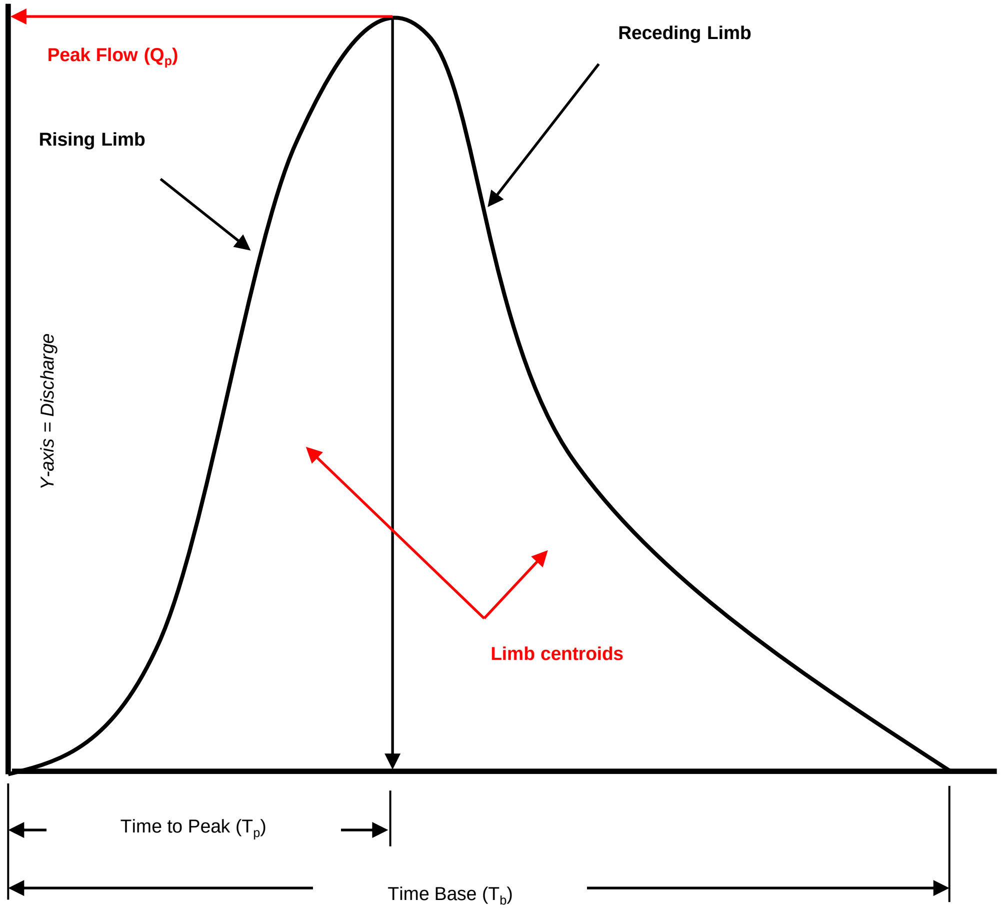
BACI: basic components (precip)



BACI: sub-basin offsets



BACI: hydrograph limbs



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BACI: response apportionment

Effects that vary with Period & Limb
but not by Basin (Main effect)

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Treatment effects vary by both Period and Basin
an interaction – one or more basins changes behavior relative to the others only during the treatment period

In typical BACI ANOVA, individual factor are treated as (orthogonal) effects

Here we include all of them in each of a set of (orthogonal) causality-groups

We "force" all non-interactive effects into the main effects by coding the interaction group with zeros during the baseline period

We checked the sufficiency of such a model to ensure that an interaction group is in fact not needed during the baseline period (using a full vs. reduced model test, for just the baseline period)

Not shown, but we also added a causality group for basin Type (Control versus Treatment), and the conclusion based on the statistical test for Treatment was the same (small magnitude but statistically significant)

- Period × Limb (change in discharge response through time common to all basins)
- Basin × Limb (discharge responses of basins that are invariant across study periods)
- Period × Basin × Limb (any treatment effects should not be captured by the previous two groups)

BACI: Effect Group Components

$$
\begin{aligned}
Y_{L,t} = {} & \text{Period} + \text{Basin} + P \cdot B \\
& + \sum_{k=t-n}^{t} \alpha_{L,t\text{-}k} \cdot R_{L,k} \\
& + \sum_{k=t-n}^{t} \alpha_{L,t\text{-}k} \cdot X_{L,k} \\
& + \sum_{k=t-m}^{t} \beta_{L,t\text{-}k} \cdot Y_{L,k} \\
& + \gamma_{L,P} \cdot \text{date-time} \\
& + \delta_{L,P} \cdot \sin(2\pi/365 \cdot \text{date-time}) \\
& \qquad \cdot \cos(2\pi/365 \cdot \text{date-time})
\end{aligned}
$$

BACI: statistical evaluation

- Ran model with and without the treatment-effect group to get a “Full” and a “Reduced” model
- Tested the full and reduced models against one another using approximate-mixture-method (akin to liklihood ratio test for fixed-effects models)
- treatment resulted in small (about 6% of total variance explained by the model) but statistically significant ($P<0.001$) decrease in discharge